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(54) Multispot polygon ros with maximized line separation depth of focus

(57) An apparatus for improving the depth of focus in a raster output scanner (ROS), and more particularly to a system for maximizing the line separation depth of focus of a multispot ROS while maintaining the system common depth of focus. The apparatus comprises: a source of at least two light beams (A,B; Fig. 1); a scanning polygon mirror having at least one facet (92); pre-scanning optics including a collimator (84), an aperture (86) and a cross-scan cylinder lens (88); and post-scanning optics including a dual element (94a,94b) f-theta scan lens (94) and a wobble correcting element. In a preferred design for a ROS-based system, the system common depth of focus (system common DOF) is maximized, where the system common DOF is characterized as the depth-of-focus over which all performance parameters are met. The optical system design achieves a desirable system common DOF while maintaining a line separation of 127 μm (1/200 inch).

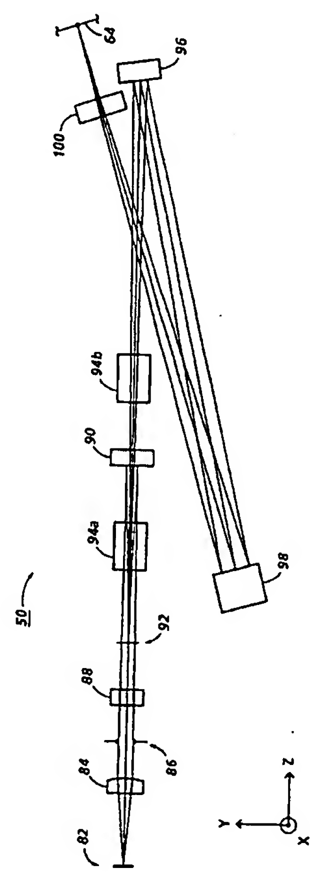

FIG. 2

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Description

This invention relates generally to a method and apparatus for improving the depth of focus in a raster output scanner (ROS), and more particularly to a system for maximizing the line separation of a multispot ROS while maintaining a substantial system common depth of focus.

The present invention is employed in a rotating polygon-based optical system. A known rotating polygon multibeam ROS scanner system is described below, for easier understanding of the technical discussion, with reference to Figure 10. It should be appreciated that the functions described below equally apply to many polygon-based systems, independently of the number of light sources used.

Figure 10 shows a pair of sagittally offset laser diodes 31 and 32. The beams 41 and 42 emitted by laser diodes 31 and 32 are collimated by collimator 33 (lens L1). A sagittal aperture 34 follows the collimator to control the F/#, which in turn controls the spot size created by the beams. The input cylinder optical element 35 (lens L2) focuses the beams 41 and 42 on the surface of a polygon facet 36 of the rotating polygon. After reflecting from facet 36, beams 41 and 42 pass through the f-Θ (f-theta) lens 37 (lens L3). The main function of the f-Θ lens 37 is to provide focusing in the tangential meridian and control the scan linearity, in terms of uniform spot displacement per unit angle of polygon rotation.

Subsequently, the motion compensating optical element (MCO) 39 reimages the focused beams 41 and 42 reflected from polygon facet 36 onto the photoreceptor (PR) plane 40 at a predetermined positions 44,43, independently of the polygon angle error or tilt of the current facet 36. The MCO can consist of a toroidal surface in the f-Θ lens, a post-polygon cylinder mirror or a post-polygon cylinder lens. Such compensation is possible because the focused beams are stationary "objects" for the f-Θ lens 37 and the MCO 39. Although, due to polygon tilt, or wobble, the beams 41 and 42 are reflected to different positions of the post-polygon optics aperture for each different facet of the rotating polygon, the beams 41 and 42 are imaged to the same position on the PR plane 40. It should be appreciated that in Prior Art arrangement of Figure 10, the chief exit rays from the MCO are not telecentric. That is, the chief exit rays are not parallel with the system axis 38.

US-A-3,750,189 to Fleischer discloses a ROS system including a laser whose single-beam, modulated output is collimated and focused onto the facets of a rotating polygon. The reflected beams pass through an fΘ lens lens system and are focused in the scan direction on the surface of a moving photoreceptor. A start-of-scan photosensor is located in the scan plane.

US-A-4,390,235 to Minoura discloses a multi-beam scanning apparatus for scanning a surface with a plurality of beam spots modulated independently of one another. Included in the system is an anamorphic afocal zoom lens which has the function of changing the angular magnification, resulting in a proportional change in the spot size as well.

US-A-4,474,422 to Kitamura discloses a multi-beam optical scanning apparatus employing a collimating portion positioned subsequent to a polygon reflector.

The main problem with the systems shown in Figure 10 and described in the related patents and publications is an inability to produce focused scan lines with sufficient line separation depth of focus to enable the use of two or more lasers, with an interlace of greater than one. This constraint to the use of an interlace of one dictates that these ROS designs will be radiometrically inefficient, since significantly more truncation of the beam is required with an interlace of one than with a higher order interlace.

"Line separation depth of focus" represents the distance along the optical axis over which the line separation is within a specified tolerance of the nominal value. This line separation depth of focus may also vary along the scan line. "Differential bow" is the variation in line separation along the scan line. Thus, differential bow is a special case of line separation, which is the more general imaging parameter. Insufficient line separation depth of focus, and therefore differential bow depth of focus, are primarily attributable to the angular deviation between the chief rays and the system axis between the MCO and the PR image plane. This angular deviation makes it difficult to maintain the line separation and differential bow over a workable depth of focus.

In rotating polygon, multiple spot ROS-based xerographic copiers and printers, it is necessary to accurately maintain the required line separation and to minimize the differential bow. Moreover, it is desirable to maximize the depth of focus for the line separation and the differential bow so as to reduce the critical tolerances for mechanical components within the copier or printer. In a preferred design for a ROS-based system, the system common depth of focus (system common DOF) is maximized, where the system common DOF is characterized as the depth-of-focus over which all performance parameters are met. More specifically, the performance parameters are intended to include at least the following five factors: (1) scan and cross-scan spot size; (2) wobble; (3) differential bow; (4) line separation; and (5) scan linearity. Maximizing the system common DOF means to simultaneously maximize the depth-of-focus for all five listed parameters.

The five performance parameters may be further described as follows:

"Spot size" is typically measured at the Full Width Half Maximum (FWHM) or at the $1/e^2$ point of the Gaussian Beam. The resolution and image processing requirements of the system determine the desired spot size. Assuming

that a 600 spot per inch (spi) (24 spots/mm) system is being designed and that the FWHM spot size is to equal the raster spacing, the desired FWHM spot size is:

(1inch/600 spots)(25.4mm/inch)(1000 μm/1 mm) = 42.3 μm round spot

Hence, the spots would overlap at the FWHM in both the scan and in the cross-scan directions. Variations in the desired spot size occur depending on whether or not the spot is pulse width modulated. For gray writing, an elliptical (anamorphic) spot may be desired (typically narrower in the scan plane than in the cross scan plane). With specially designed electronics the spot may be controlled by pulse width modulation to the desired size within the raster spacing and thus the desired gray level.

"Wobble" is the unequal spacing of successive scanlines in the process direction at the image plane. Wobble appears to the human eye as banding in a final print. The presence of wobble can be quite disturbing if it occurs within a frequency range over which the eye is most sensitive (typically 0.5 to 2.0 cycles/mm). Therefore, wobble correction is essential over this frequency range in ROS designs. Wobble is directly related to the amount of pyramidal error in the polygon facets. A physical (mechanical) facet tilt of ±0.5 minute (30 arcseconds) produces a ±1 minute (60 arcseconds) of optical tilt.

"Bow" is a measure of the curvature in the cross-scan direction of the scan line from one end of the scan to the other. Bow may be calculated by taking the average of the cross-scan heights at the extreme ends of the scanline then subtracting the cross-scan height at the center of scan. In a multiple diode system, each diode source has its own bow curve. It is the maximum difference in the bow curves between the multiple diodes in a given system that defines the "differential bow". Typically, the bow specification in black-only machines may be quite large, on the order of 150-200 μm. However, the differential bow specification must be held much tighter.

The required "line separation" is dependent on the desired interlace factor. For a scan line interlace factor of 3 for 600 spi (24 spots/mm) raster spacing the line separation is 127 μm.

The optical design must achieve f-Θ correction in the optics to ensure the "scan linearity." Scan linearity is the measure of how equally spaced the spots are written in the scan direction across the entire scanline. Typical scan linearity curves start at zero position error at one end of a scan having a positive lobe of position error, cross the center of scan with zero position error and then have a negative lobe of position error toward the other end of the scan. Scan linearity curves may have image placement errors of zero at several locations across the scanline. Ideally, the curve would be at zero across the entire scanline.

Although a multi-beam, laser diode based ROS is viewed as a most powerful technology for high quality, high throughput xerographic printing, the necessity for high tolerance mechanical systems to eliminate or control the above effects within the xerographic engine is a barrier to increased speed and reduced cost for such systems. Accordingly, the present invention is directed at a ROS system that not only achieves the desired line separation, enabling higher throughput levels, but does so while maintaining substantial system common depth of focus, thereby reducing the tolerance for other xerographic engine components, such as the photoreceptor and facilitating the alignment process.

In accordance with the present invention, there is provided a multispot optical scanning system for exposing a surface of a photoreceptor, comprising: a source of at least two high intensity modulated light beams; a reflective scanning member, having a light reflective surface thereon, interposed in the optical path between said source and the surface of the photoreceptor; a pre-scanning optical system for directing the beams to the light reflecting surface of the reflective scanning member, said pre-scanning optical system including a collimator, an aperture, and a cross-scan cylinder lens; and a post-scanning optical system for placing the beams reflected from the light reflecting surface of said reflective scanning member in a path telecentric with an optical axis of the post-scanning optical system prior to striking the surface of the photoreceptor so as to maximize the system common depth of focus about a focal plane defined by the photoreceptor surface, said post-scanning optical system including an f-theta scan lens, and a wobble correcting element.

Embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a block diagram illustrating a preferred multiple beam ROS embodiment for the present invention;
Figure 2 is a folded cross scan plane view of the elements comprising the present invention;
Figure 3 is a folded scan plane view of the elements comprising the present invention;
Figure 4 is a detailed cross scan plane view of the pre-scanning ROS elements of Figure 1;
Figure 5 is a detailed scan plane view of the pre-scanning ROS elements of Figure 1;
Figure 6 is a detailed cross scan plane view of the pre-scanning ROS elements of Figure 1;
Figure 7 is a detailed scan plane view of the pre-scanning ROS elements of Figure 1;
Figure 8 is a detailed view of the line separation and depth of focus available as a result of the present invention in the area near the photoreceptor plane;
Figure 9 is a graphical illustration of the relationship of line separation versus depth of focus for a preferred embodiment of the present invention; and

Figure 10 shows the sagittal block diagram of a typical prior art polygon optical system.

For a general understanding of the present invention, reference is made to the drawings. In the drawings, like reference numerals have been used throughout to designate identical elements. In describing the present invention, the term pixel will be utilized. The term pixel refers to an optical (or electrical) signal representing the measurable optical properties of a physically definable region on a display medium. A plurality of physically definable regions for either situation represents the physically measurable optical properties of the entire image preferably rendered by a material marking device, or alternatively electrical and magnetic marking devices, or an optical display device.

Figure 1 is a block diagram illustrating a preferred multiple beam ROS embodiment for the present invention. More specifically, a dual laser diode driver 54 receives input video signals from a video image source 52 such as a raster input scanner (RIS) or similar system suitable for the generation of video signals, including computers, facsimile scanners, and networks. In response to the video signals, the driver 54 causes the modulation of the dual beams (A and B) of multiple laser diode 56. Subsequently, the modulated, dual-beam output of multiple laser diode 56 is shaped by pre-scanning optics 58 before being reflected from a facet 92 of polygon mirror 60. After reflection, the dual-beams are again shaped by post-scanning optics 62 before being scanned across the surface of photoreceptor 64 as a set of beams separated at the surface of the photoreceptor 64 by distance d.

Table 1 below outlines the general specifications for the telecentric ROS optical system in accordance with the present invention and as depicted in Figures 1-7.

TABLE 1

RESOLUTION:	600 spots/inch (spi) (24 spots/mm)
SCAN LENGTH:	12.2 inch (310 mm)
NUMBER OF LASERS:	2
LASER ORIENTATION:	cross scan (sagittal) offset
LASER SEPARATION:	25 μm
INTERLACE FACTOR:	3
SCAN LINE SEPARATION:	3×1/600 inch (127 μm)
SCAN LINE SEPARATION TOLERANCE RANGE:	up to ± 10.0 μm, and preferably less than ± 4.0 μm

As shown in Table 1, the design specifications for the preferred optical system shown in Figures 1-7 require a resolution of 600 pixels per inch (24 spots/mm), over a scan line of 12.2 inches (310 mm). Two laser diodes are employed. The laser diodes are vertically aligned into a column, and offset in the cross scan direction (vertically) by 25 μm. The laser beams (A,B) emitted by the laser diodes are used to form an interlaced image having a scan line interlace factor of 3, where the scan line separation between adjacent scan lines is 127 μm. Alternatively, the scan lines can form consecutive, or in-pitch, scan lines, thus forming a block of text during each scan.

Figures 2 and 3 illustrate a preferred embodiment forming a general solution for the previously described shortcomings. The cross scan plane and scan plane views of the ROS apparatus 50, respectively illustrated in Figures 2 and 3, include a pair of laser diodes (not shown) that emit a pair of light beams A and B through diode window 82. The light beams A and B pass through a collimator 84 and pass through cross scan aperture stop 86. Collimator 84 preferably comprises a single element collimator having one aspheric surface and one spherical surface. Alternatively, collimator 84 may be a multiple element collimator or a gradient index (GRIN) lens. The light beams then continue through a single element cross-scan cylinder lens 88 which focuses them in the cross-scan direction onto the polygon facet surface 92 of the underfilled polygon 60 (Figure 1) after being reflected off of a first fold mirror 90. After being reflected and scanned by the polygon facet surface 92, the light beams A and B pass through the f-Θ (f-theta) scan lens 94. The f-Θ scan lens 94 is preferably a two-element lens, as depicted in Figure 3, comprising a first scan lens 94a and a second scan lens 94b. Details of the f-Θ scan lens as well as other elements of the optical system are included in Table 2. Alternatively, the f-Θ (theta) scan lens 94 may be a single aspheric toroid lens.

TABLE 2 -

Description of Optical Elements				
Comment	Element	Glass Type	Surface Types	
			Surface 1	Surface 2
flat window which comes in diode	Diode Window	FK5	plano	plano
collimator element	Aspherical Lens	PSK50	spherical	aspherical
rectangular	Aperture Stop	N/A	N/A	N/A
pre-polygon cylinder lens	Cylinder Lens	BK7	cross scan plane cylinder	plano
fΘ lens 1	Scan Lens #1	PBH10	scan plane cylinder	cross scan plane cylinder
fΘ lens 2	Scan Lens #2	PBH10	cross scan plane cylinder	spherical
5.5 degree included angle	Cylinder Mirror	BK7	cross scan plane cylinder	N/A
1 degree tilt	Exit Window	BK7	plano	plano

After the f-Θ lens 94, the light beams A and B are reflected by a second fold mirror 96, and then reflected by a cylinder mirror 98 prior to passing through exit window 100. Once through exit window 100, the light beams impinge upon photoreceptor surface 64 forming two spots, respectively 104 and 106, as illustrated in Figure 8. The two spots each produce a scan line of at least 12 inches (30 cm) (i.e., at least a page width) when scanned across the photoreceptor surface 64 by the rotating polygon.

Referring now to Figures 4 and 5, the details of the pre-scanning optical system, optics system 58 of Figure 1, will be described in further detail. Although not shown in Figures 4 or 5, the dual beams A and B are preferably generated by a dual diode laser or any equivalent device having a flat diode window 82. The dual diodes are separated by a distance of approximately 25 μm, and are oriented in the optical system so that they are offset in the cross scan direction. Once the beams are transmitted through window 82, they are next transmitted by aspherical lens 84, which serves to collimate the beams. Lens 84 preferably exhibits a spherical shape on the diode side and an aspherical shape on the facet side thereof. In a preferred embodiment, the aspherical lens may be formed of PSK50 glass as indicated in Table 2.

Once transmitted through the aspherical collimating lens 84, the beams are then passed through an aperture or rectangular stop 86, where a portion of the beam intensity may be attenuated. The major axis of the rectangle is in the scan plane and the minor axis of the rectangle is in the cross-scan plane. Beams A and B are then operated on by cylinder lens 88. Cylinder lens 88 preferably includes a first surface which may be characterized as forming a cross scan plane cylinder, and a second or output-side surface that is planar. The focal length and position of the cylinder lens serves to focus the beams in the cross scan plane plane at the facet surface 92. The beams remain collimated in the scan plane plane at the facet.

Having been focused in the cross scan plane plane by cylinder lens 88, the beams are then reflected off the planar surface of the first fold mirror 90, in the direction of the facet 92. Fold mirror 90 is positioned at a 60° included reflected angle in the folded optics system illustrated (see Fig. 3) for the preferred embodiment. Having traversed the elements of the pre-scanning optical system, the beams reflected off of first fold mirror 90 are then reflected by a surface of polygon 60 in Figure 1, illustrated in Figures 4 and 5 as facet 92. In a preferred embodiment, polygon 60 may be characterized as an underfilled, 8 facet design.

It should be appreciated that the reflecting surface need not be a rotating polygon facet. The surface can also be a reflecting surface associated with a galvanometer, a holographic scanner or a micromodulator as are well-known in the art. The rotating polygon may have any number of facets, from one to as many as necessary to obtain the desired system characteristics. Further, the reflecting surface, whether a rotating polygon, a micromodulator, or any other known type of scanning mechanism, can be of a type that is underfilled by the light beams, or overfilled by the light beams, or critically filled. In addition, although not illustrated, an enclosure with a window or similar means for preventing contamination of the facet surface(s) may be employed to isolate the reflecting surface(s).

Turning now to Figures 6 and 7, in conjunction with Table 2, the details of the post-scanning optics system will be

described. Specifically, the f-Θ scan lens 94 is comprised of two elements, a first scan lens 94a and a second scan lens 94b. First scan lens 94a has scan plane cylindrical power on surface 112 which faces the polygon facet, and cross scan cylindrical power on the opposite surface, 114. Second scan lens 94b of the f-Θ lens 94 has cross scan cylindrical power on surface 1 18 and spherical power on surface 120. The chief rays for each of the beams, A and B, are illustrated in their respective positions as they pass through the two elements of f-Θ lens 94.

Subsequently, the beams are reflected by a second fold mirror 96 which is angled at approximately 6.25 degrees to the cross scan axis so as to direct the beams to the reflecting surface of cylinder mirror 98 at an included angle of 12.5 degrees. Cylinder mirror 98 is angled at 2.75 degrees with respect to the optical axis, yielding an included angle of 5.5 degrees, and directs the beams toward exit window 100 upon reflection therefrom. The sole purpose of exit window 100 is to isolate the optical system 50 from the remainder of the xerographic engine, keeping dirt out of the ROS optical subsystem. After passing through exit window 100, the beams impinge upon the surface of photoreceptor 64 to form a pair of parallel lines as they are scanned across the surface.

It should be noted that while illustrated as a dual-beam ROS for simplicity, optical system 50 is equally applicable to systems having three or more laser diodes and laser beams. It should also be noted that in the case of an odd number of lasers, the chief ray of the center laser would be located on the cross scan optical axis.

It should further be appreciated that each laser diode can emit its light beam at a wavelength different from that of the other. Finally, the system is not limited to laser diodes. Any known light emitting device, such as any solid state laser, gas laser, liquid laser or semiconductor laser can be used. Further, a light emitting diode or the like may be used, so long as the emitted light beam can be modulated (either as it is output, or by a micromodulator-type scanner). Thus, a flash lamp or the like could also be used as the light source.

As illustrated in detail in Figure 8, after being reflected by cylinder mirror 98, the laser beams A and B are focused onto the plane of photoreceptor 64 to form scanning spots 104 and 106. Most importantly the chief exit rays of the laser beams A and B are essentially parallel to the system optical axis Q-Q'. That is, the chief exit rays are generally telecentric- wherein they each impinge upon the surface at an angle of incidence of approximately 0.22 degrees or less.

Finally, Figure 9 is an illustration of the line separation versus the focal position. From this graph one can calculate the line separation depth of focus (DOF) for any given line separation tolerance specification. For example the line separation DOF for a line separation specification of 127.0 ± 4.0 μm is 7.966 mm (from -4.616 mm to 3.350 mm). Table 3 shows the approximate line separation DOF's for several line separation tolerance (Δd) requirements. With such a large depth of focus, while maintaining the necessary line separation, the present invention provides significant latitude (at least 995 × Δd) in mechanical tolerances for, for example, the photoreceptor and its associated drive mechanisms.

TABLE 3

TOLERANCE (Δd) ON LINE SEPARATION SPECIFICATION Nominal = 127.0 μm (μm)	APPROXIMATE LINE SEPARATION DOF (mm)
± 1.0	1.992
± 2.0	3.98
± 3.0	5.975
± 4.0	7.966
± 5.0	9.958
± 6.0	11.949
± 7.0	13.941
± 8.0	15.933
± 9.0	17.924
± 10.0	19.916

In recapitulation, the present invention is a method and apparatus for maintaining the line separation of a multispot ROS while maximizing the system common depth of focus. In the preferred design for a ROS-based system, the system common depth of focus (system common DOF) is maximized, where the system common DOF is characterized as the depth-of-focus over which all performance parameters are met. The optical system design of the present invention maximizes the system common DOF while obtaining a line separation (d) of 127 μm. The importance of the present invention increases as the tolerance on the line separation specification decreases for high quality printing. When the tolerance is large, the resultant line separation DOF is typically acceptable from any good multiple diode design.

Claims

1. A multispot optical scanning system for exposing a surface of a photoreceptor (64), comprising:

   a source (56) of at least two high intensity modulated light beams (A,B);
   a reflective scanning member (60), having a light reflective surface (92) thereon, interposed in the optical path between said source (56) and the surface of the photoreceptor (64);
   a pre-scanning optical system (58) for directing the beams to the light reflecting surface (92), said pre-scanning optical system including

   a collimator (84),
   an aperture (86), and
   a cross-scan cylinder lens (88); and

   a post-scanning optical system (62) for placing the beams reflected from the light reflecting surface (92) in a path telecentric with an optical axis (Q-Q') of the post-scanning optical system prior to striking the surface of the photoreceptor (64) so as to maximize the system common depth of focus about a focal plane defined by the photoreceptor surface, said post-scanning optical system (62) including

   an f-theta scan lens (94), and
   a wobble correcting element (98).

2. The system of claim 1, wherein said (84) is a single element collimator having:

   an aspheric surface; and
   a spherical surface.

3. The system of claim 2, wherein said f-theta scan lens (94) includes:

   a first element (94a) having a scan plane cylindrical power on a first surface (112) facing said reflecting scanning member and a cross scan cylindrical power on an opposite surface (114); and
   a second element (94b) having a cross scan cylindrical power on a first surface (118) facing said first element and spherical power on an opposite surface (120).

4. The system of claim 1, 2 or 3, wherein said source (56) comprises a pair of laser diodes that are offset in the cross scan plane by 25 μm.

5. The system of any of claims 1 to 4, wherein said pre-scanning optical system (58) is a folded system and further includes at least one fold mirror (90).

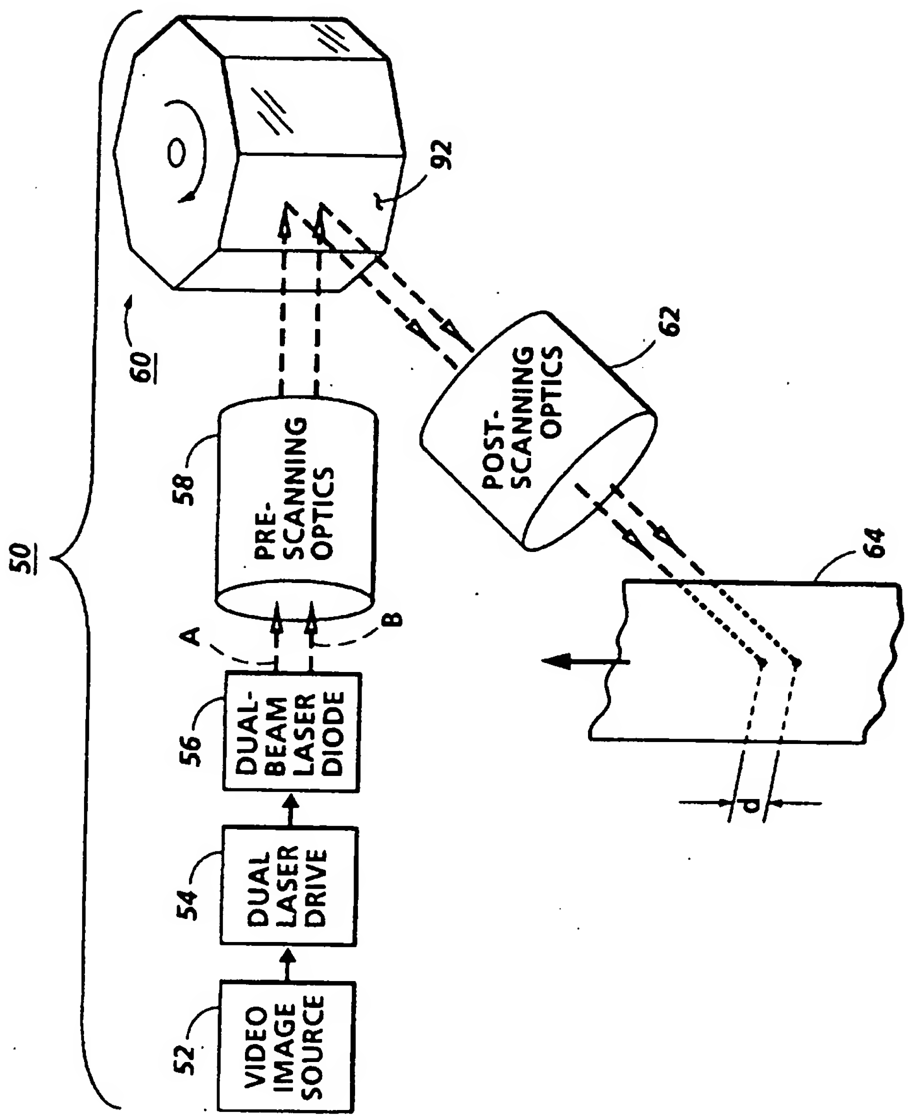
6. The system of claim 5, wherein said post-scanning optical system (62) is a folded system and further includes at least one fold mirror (96).

7. The system of any of the preceding claims, wherein said reflective scanning member (60) comprises (1) a rotating polygon, said rotating polygon preferably including eight facets spaced about a periphery thereof, or (2) a micro-modulator.

8. The system of any of the preceding claims, wherein said collimator (84) comprises (1) a GRIN lens, or (2) a multiple element collimator.

9. The system of any of the preceding claims, wherein said cross-scan cylinder lens (88) comprises a multiple element lens.

10. The system of any of the preceding claims, wherein said wobble correcting element (98) is selected from the group consisting of: a cylinder mirror; a cylinder lens; and a toroid lens.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52
VIDEO IMAGE SOURCE
54
DUAL LASER DRIVE
56
DUAL-BEAM LASER DIODE
A
B
58
PRE-SCANNING OPTICS
60
92
62
POST-SCANNING OPTICS
64
d

FIG. 1

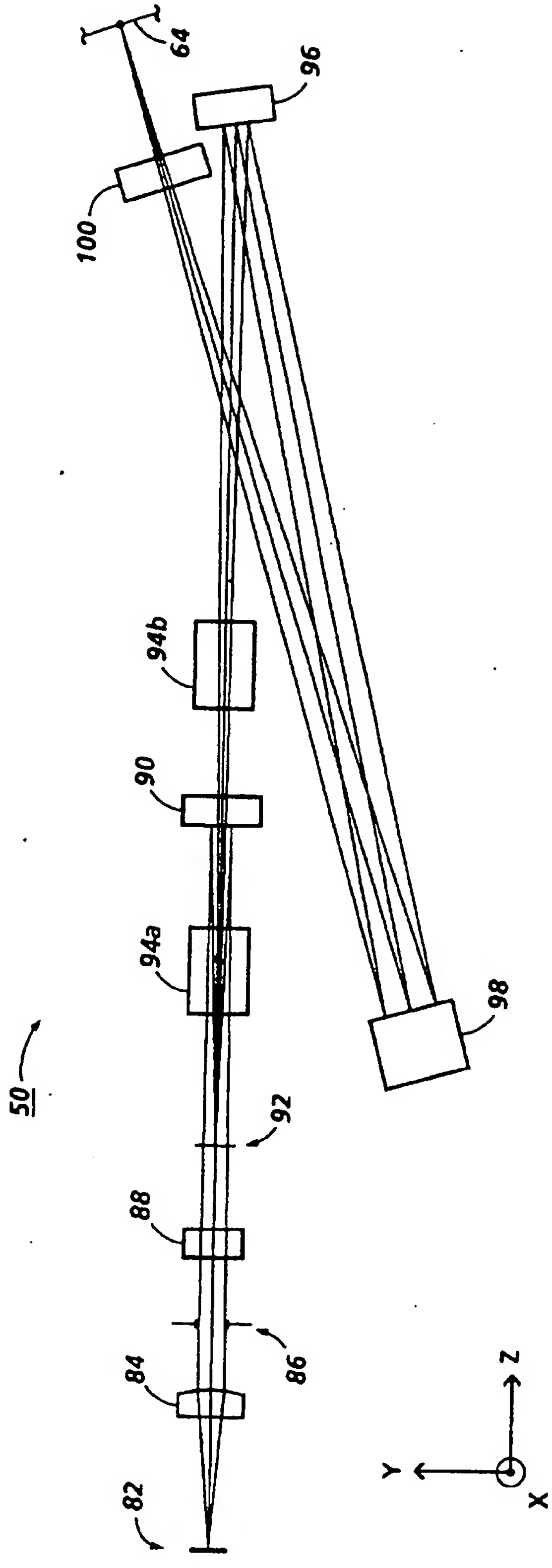
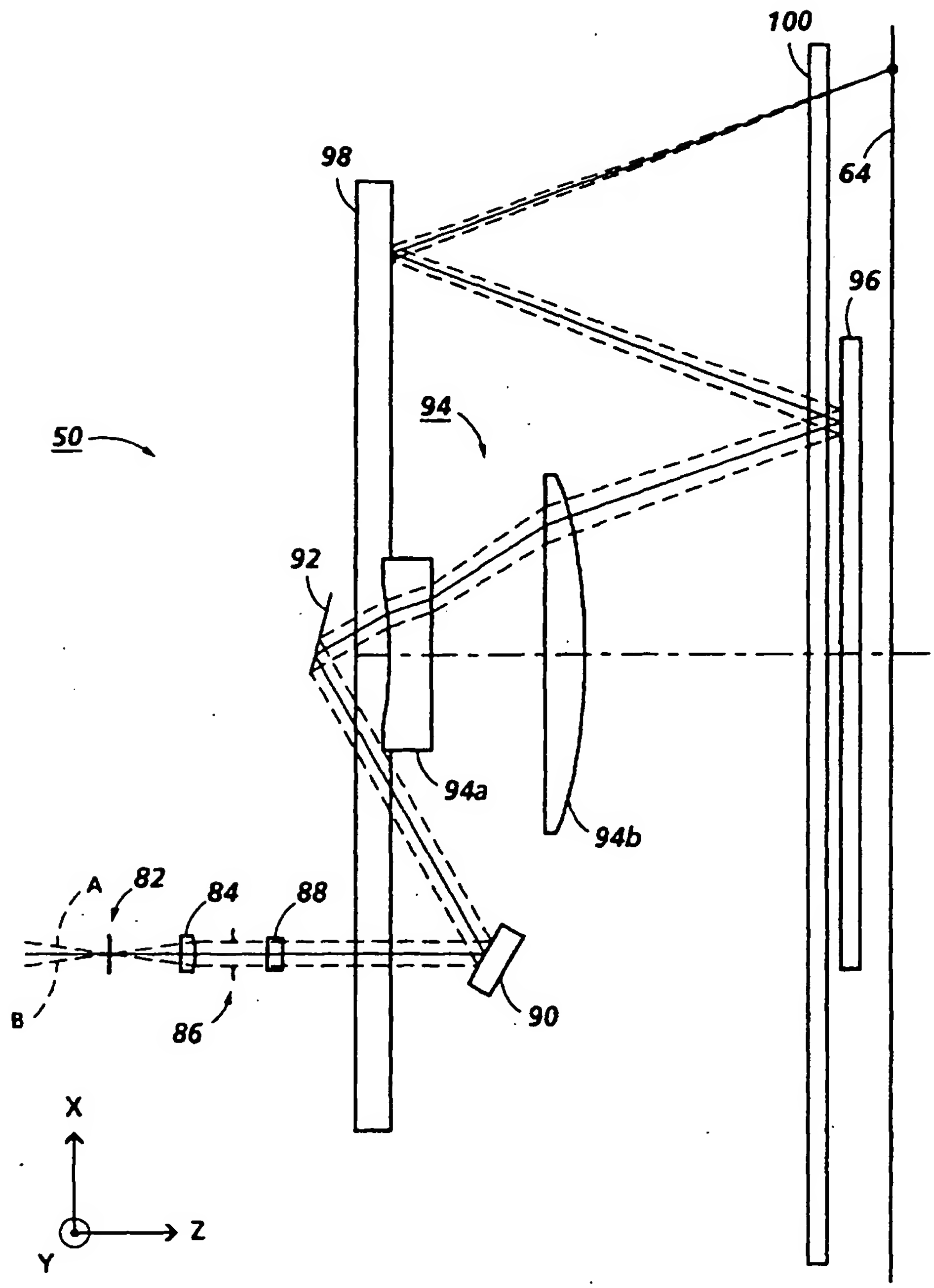


FIG. 2

FIG. 3



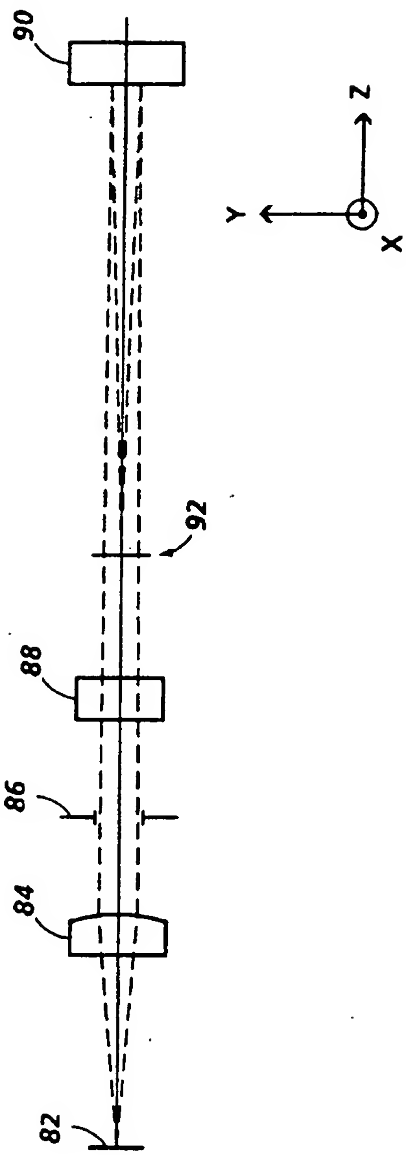


FIG. 4

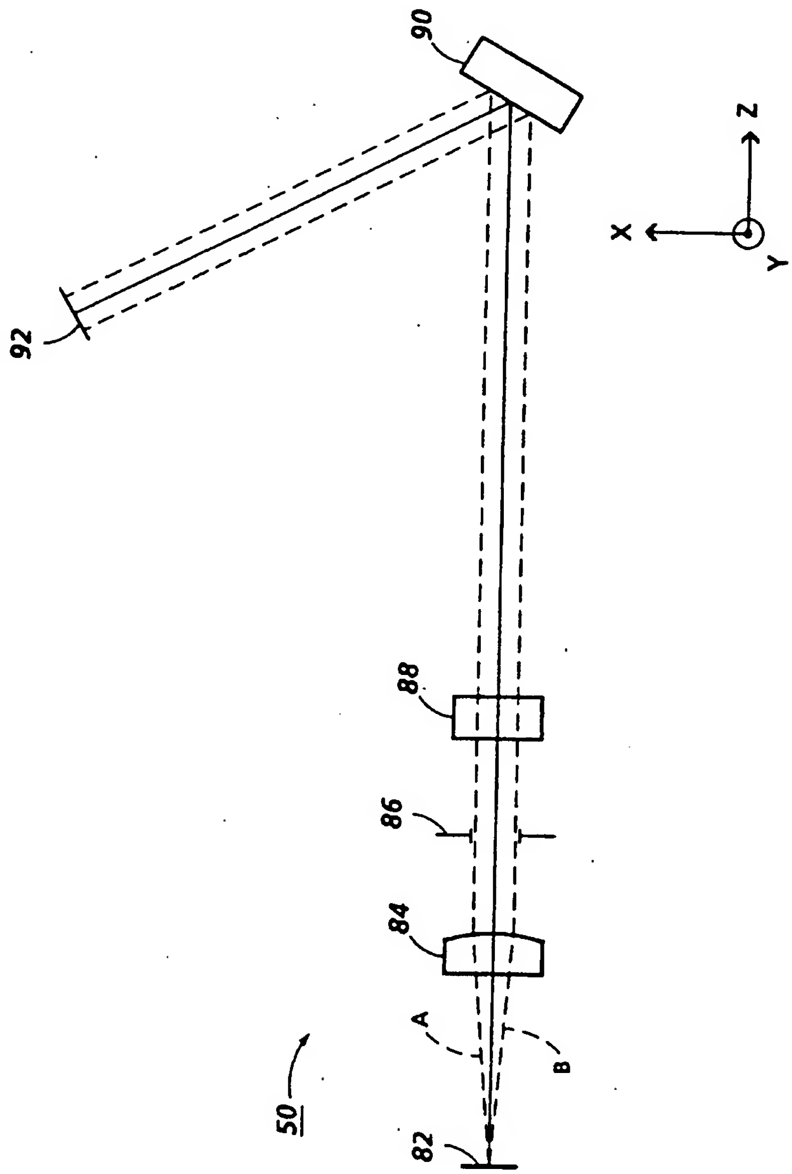


FIG. 5

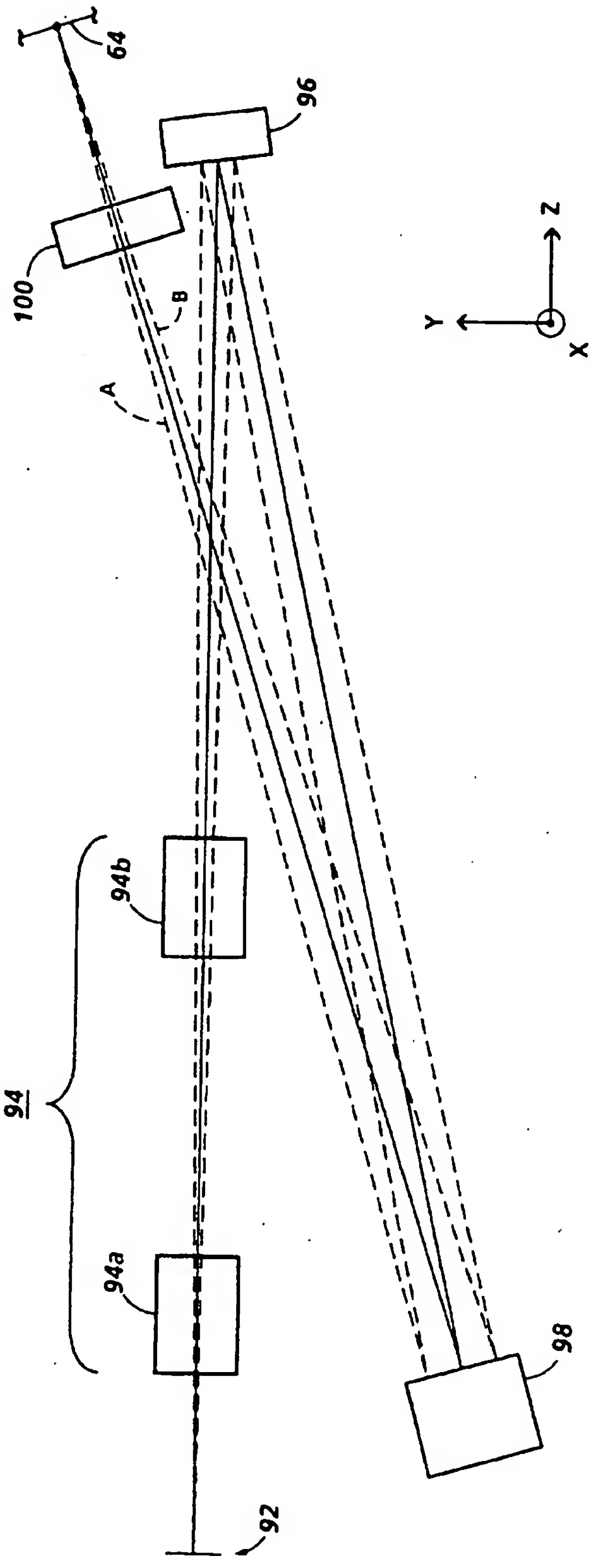
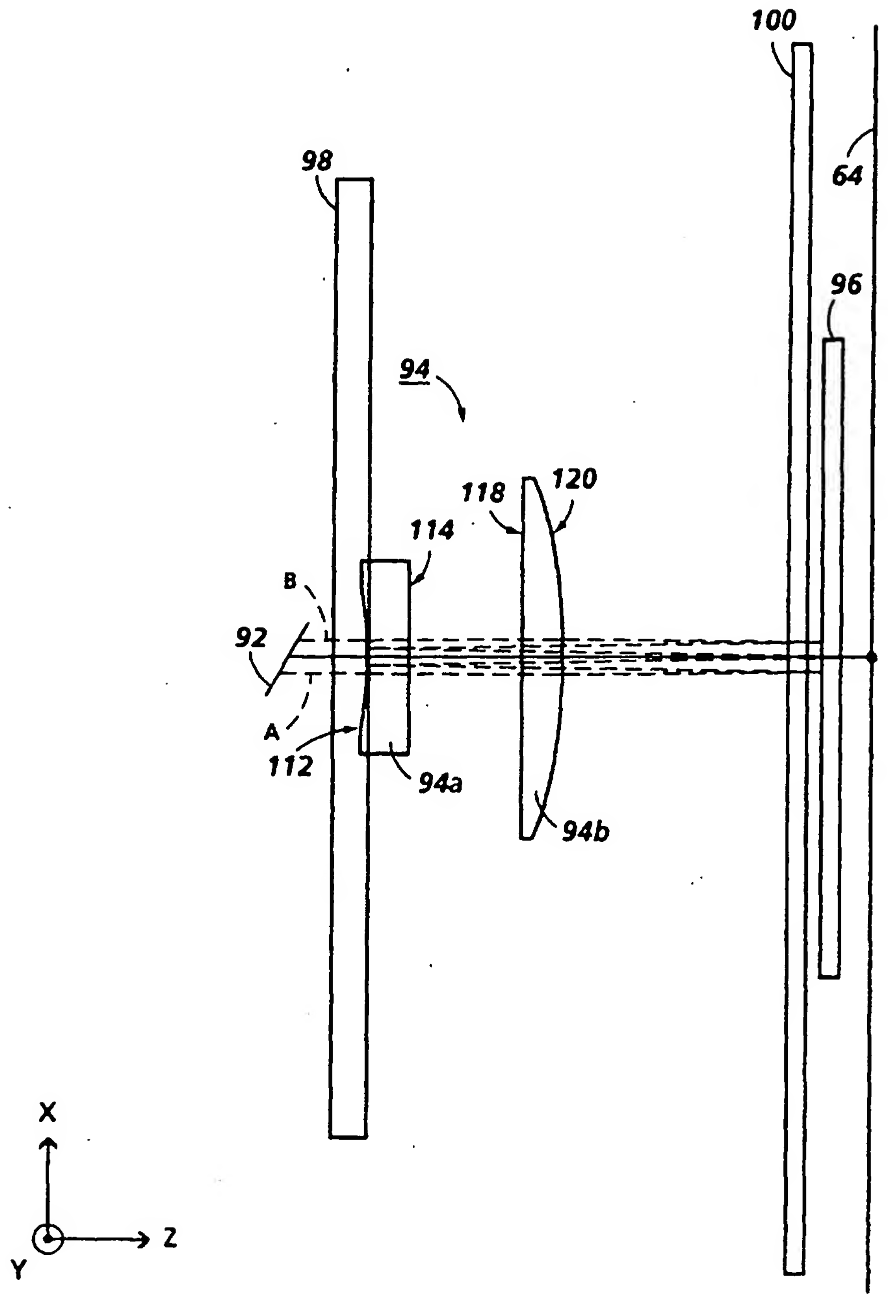


FIG. 6

FIG. 7



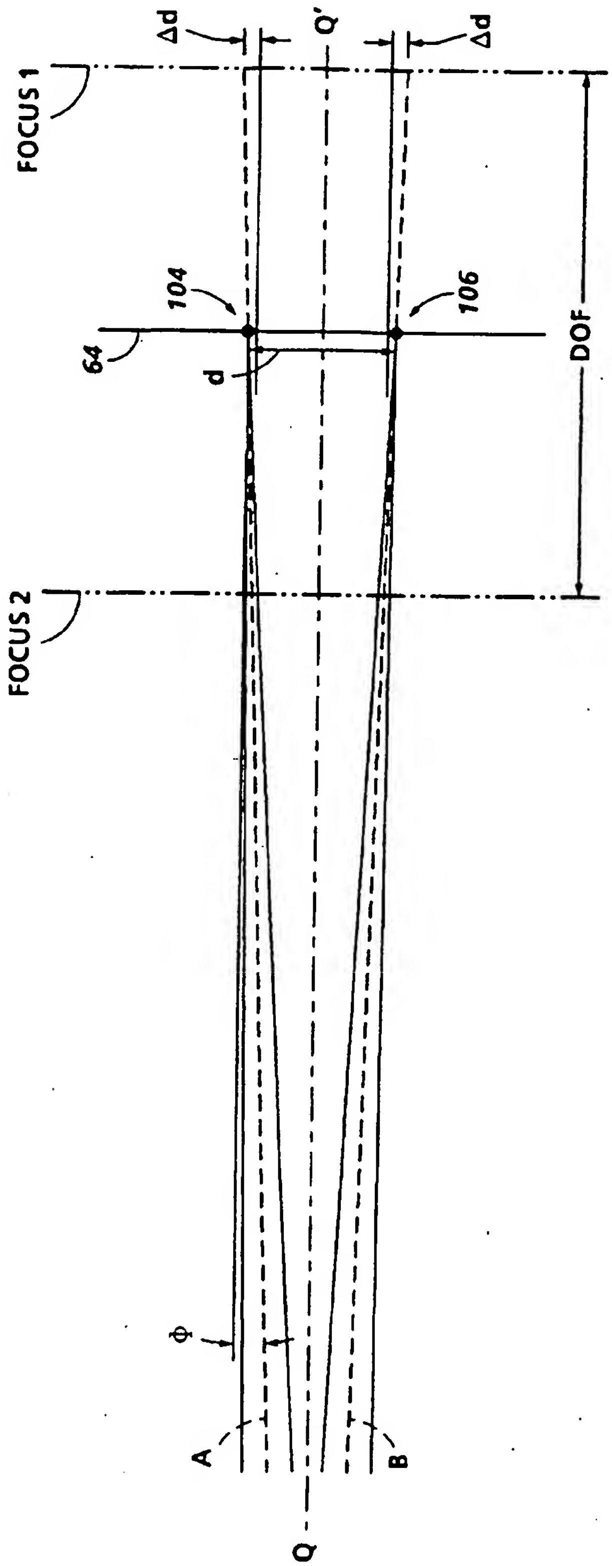
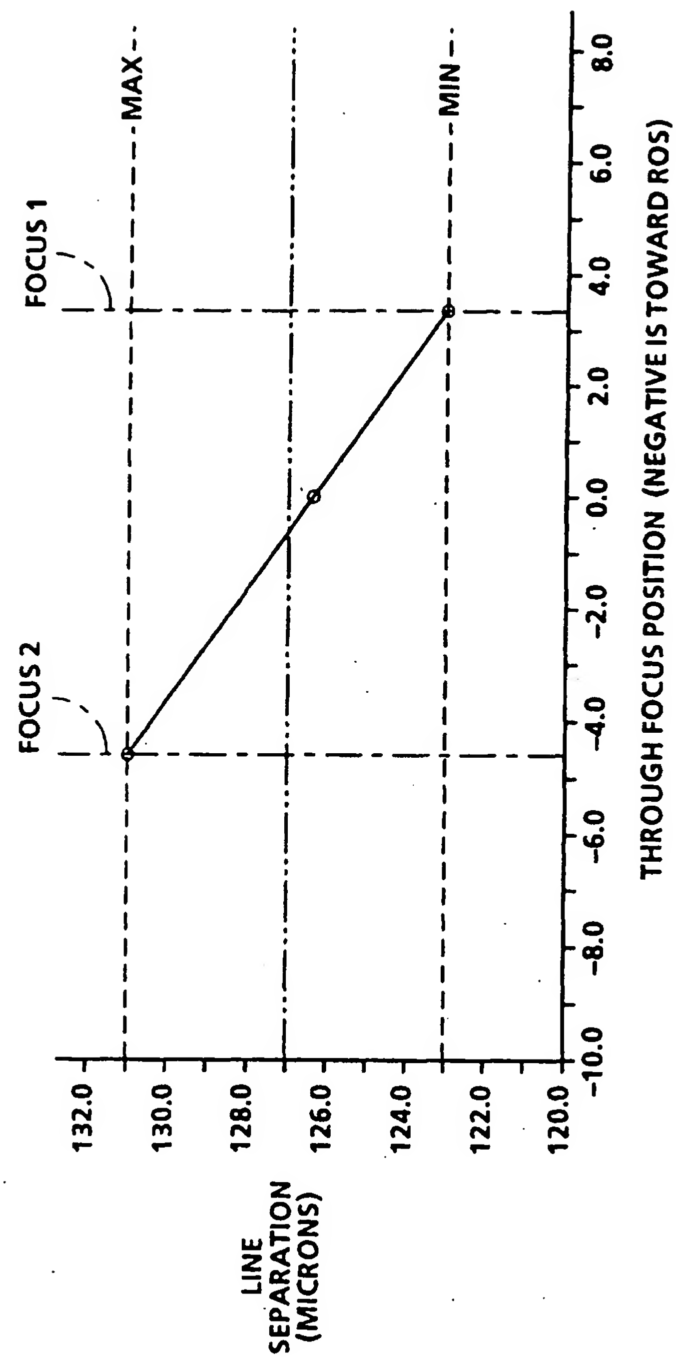


FIG. 8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FOCUS 2
MAX
MIN
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-8.0
-6.0
-4.0
-2.0
0.0
2.0
4.0
6.0
8.0
THROUGH FOCUS POSITION (NEGATIVE IS TOWARD ROS)

FIG. 9

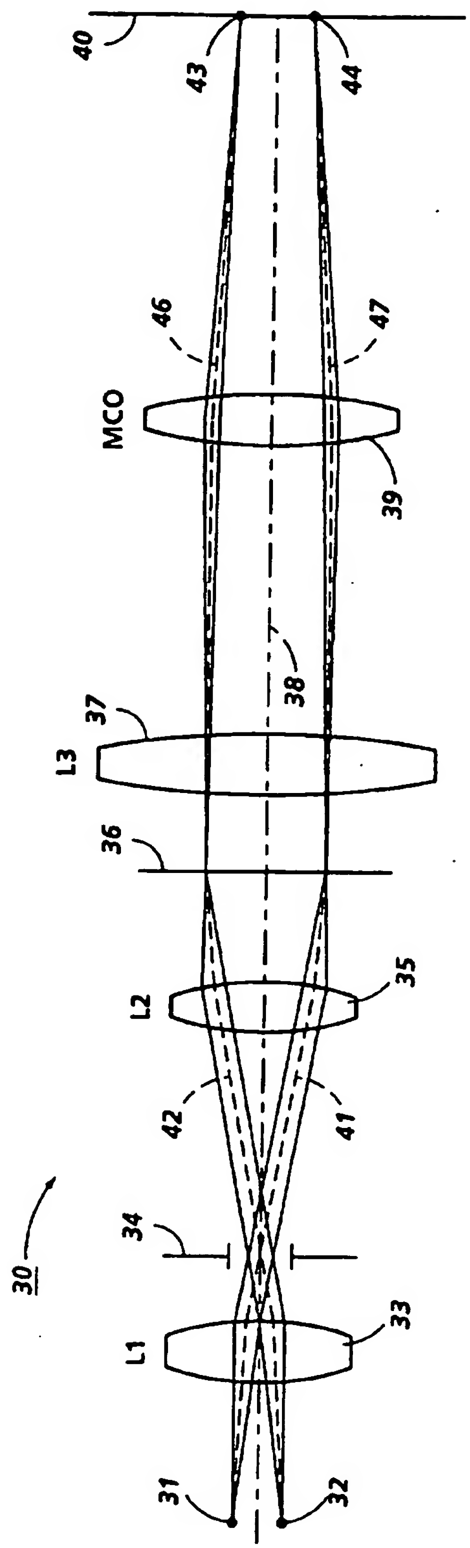

FIG. 10 PRIOR ART